An examination of the GFDL GCM using AIRS spectrally resolved radiances

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Satellite Vs. Model

- **Aqua:**
  - Sun synchronous satellite
  - Equator crossing time: 1:30am/pm
  - Circles the globe every 98m
  - Precession cycle: 16 days, i.e. ~1.5 degree westward per circle

- **AIRS:**
  - Nadir resolution ~ 15km
  - 90 samples per 8/3s
  - ~ 10 million nadir ($-5^o<\theta<5^o$) spectra per month
  - L1B: Total-sky
  - L2 cloud-cleared: Clear-sky

- **GCM**
  - GCM: GFDL AM2 forced by observed SST and radiative gases
  - 25-level (up to ~ 3hPa) temperature/moisture/cloud profiles output 3-hourly at each model grid
  - Spatial: 2.5^o x 2^o
  - Temporal: 3 hourly
  - ~ 3 million spectra per month

- **Radiative Transfer Models**

1. MODTRAN
  - Very narrow band model with a nominal resolution of 2 cm^{-1}
  - 5 extra levels (up to 100 km) of standard atmosphere patched atop the AM2 profiles

2. SARTA
  - Parameterized for each AIRS channel
  - 100 fixed model layers (gaps filled with standard profiles)
  - Only applicable for clear-sky so far

Note 1: Satellite tracking

Satellite tracking is necessary for an appropriate satellite-model comparison.

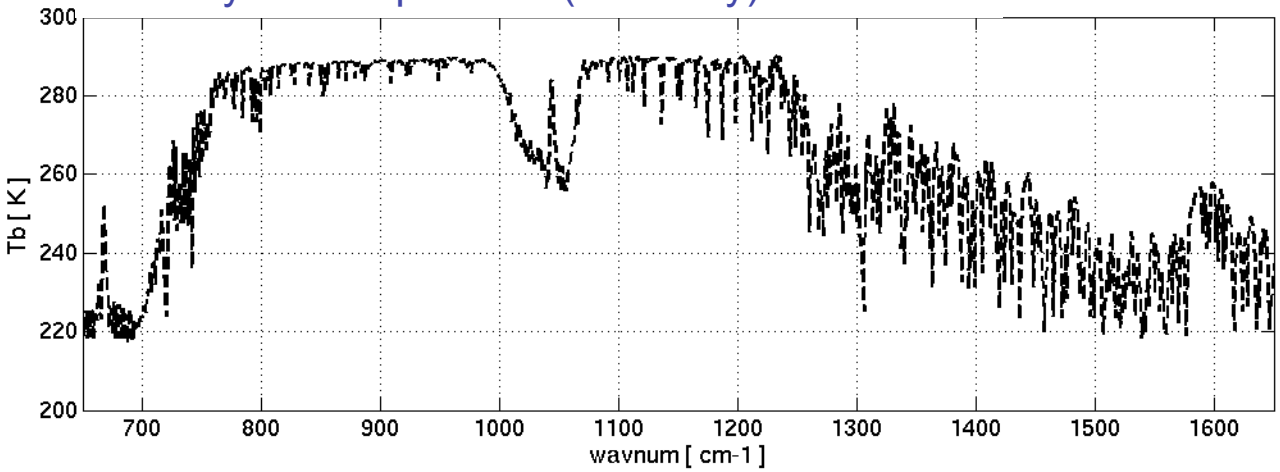
Monthly mean

– average of instantaneous spectra computed from the instantaneous profiles output at all the GCM grid points and time steps.

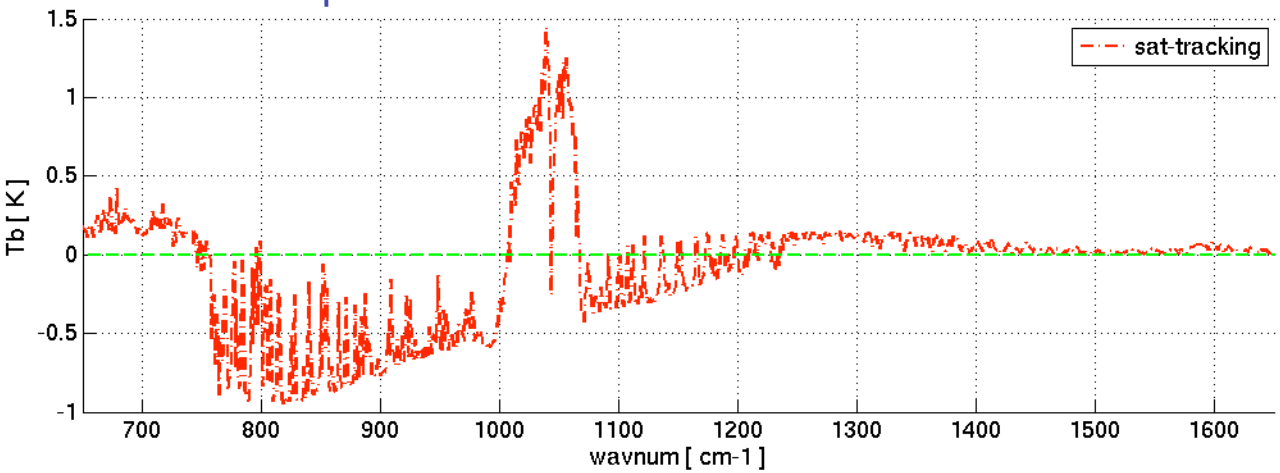
Satellite tracking

– only those grid points that are over-passed by satellite at two local times are sampled.

Monthly mean spectrum (clear-sky)



Difference spectrum

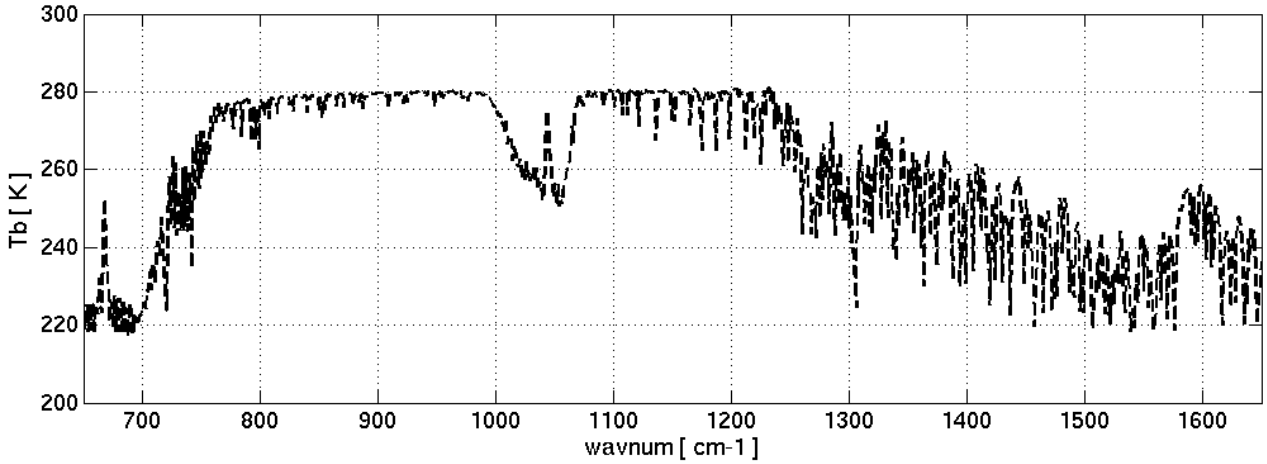


Note 2: Shortcut by using the mean profile

Using monthly mean profiles to compute monthly mean spectrum induces large errors.

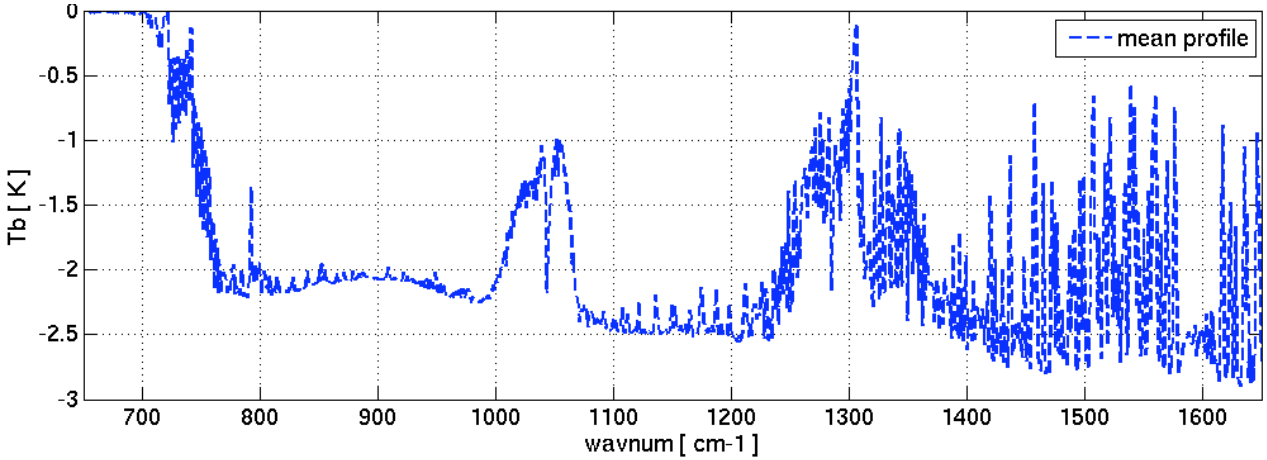
Monthly mean – average of instantaneous spectra.

Monthly mean spectrum (total-sky)



Monthly mean – computed from monthly mean T/q/cloud profiles.

Difference spectrum

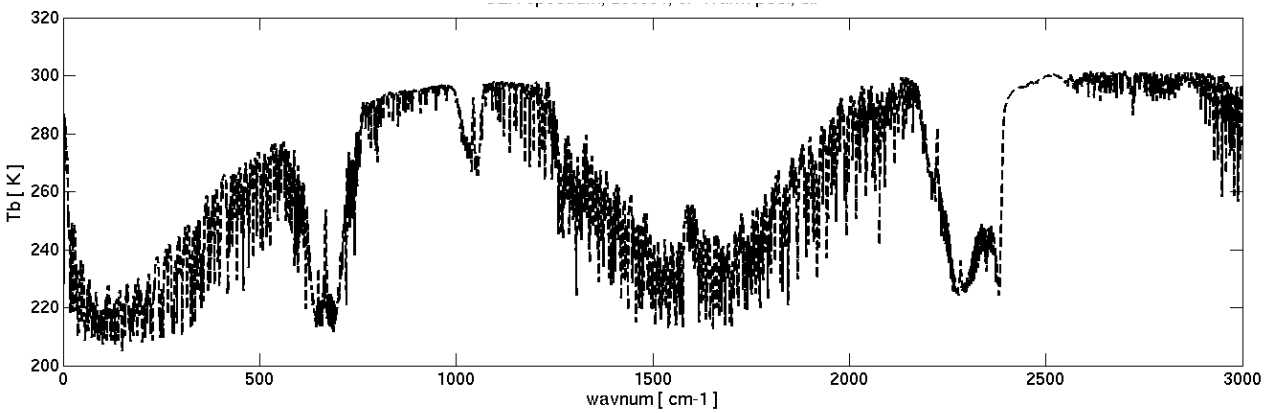


Note 3: Cloud overlap

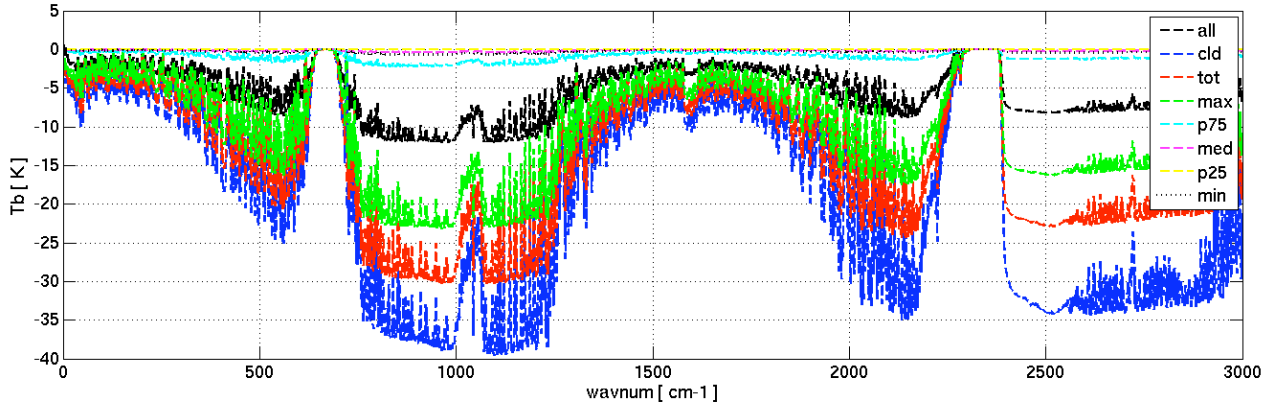
Treatment of cloud overlapping is crucial to the total-sky spectrum simulation!

- Random overlap is adopted here to be consistent with the GCM integration.

Clear-sky spectrum



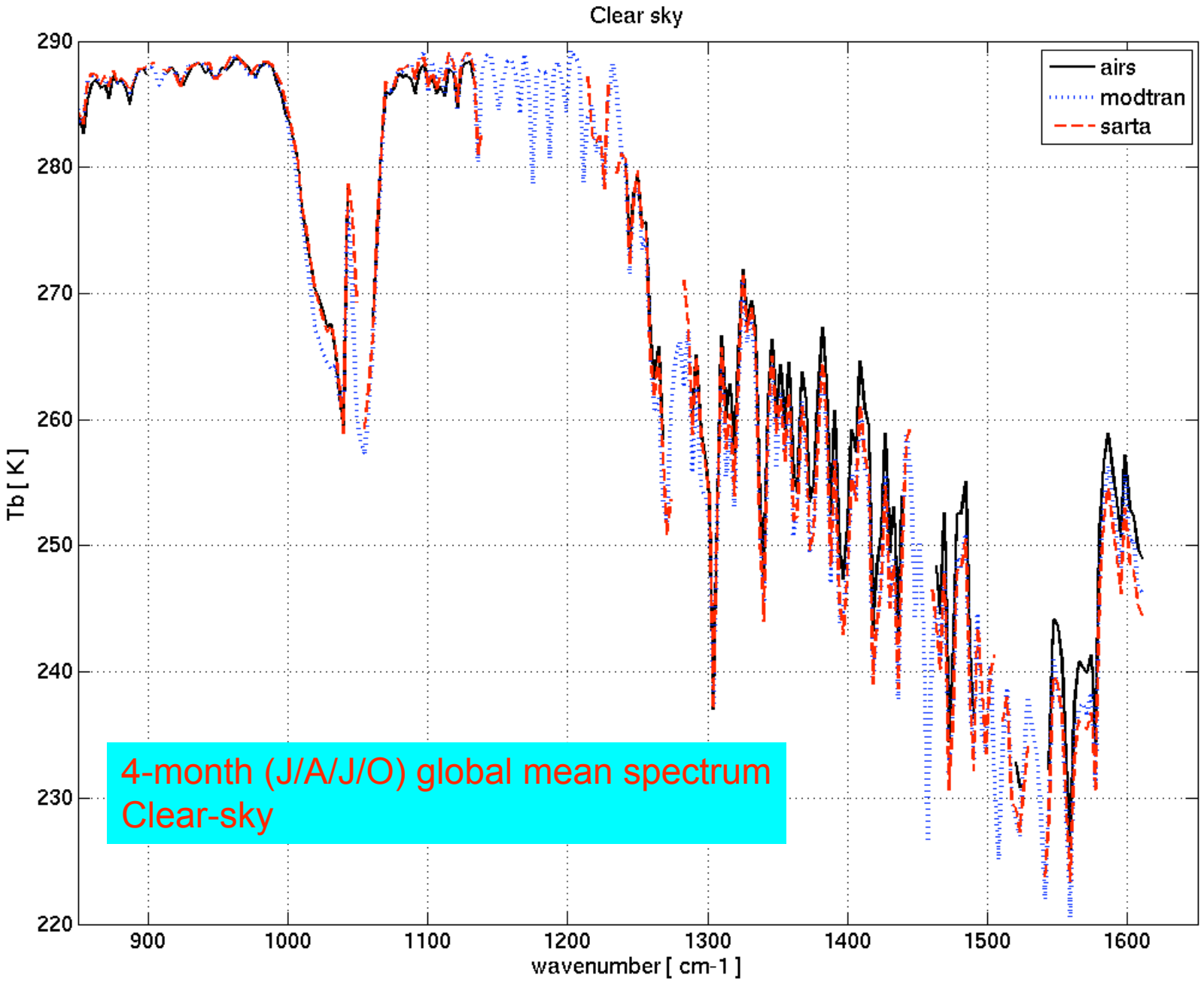
Total-sky minus Clear-sky

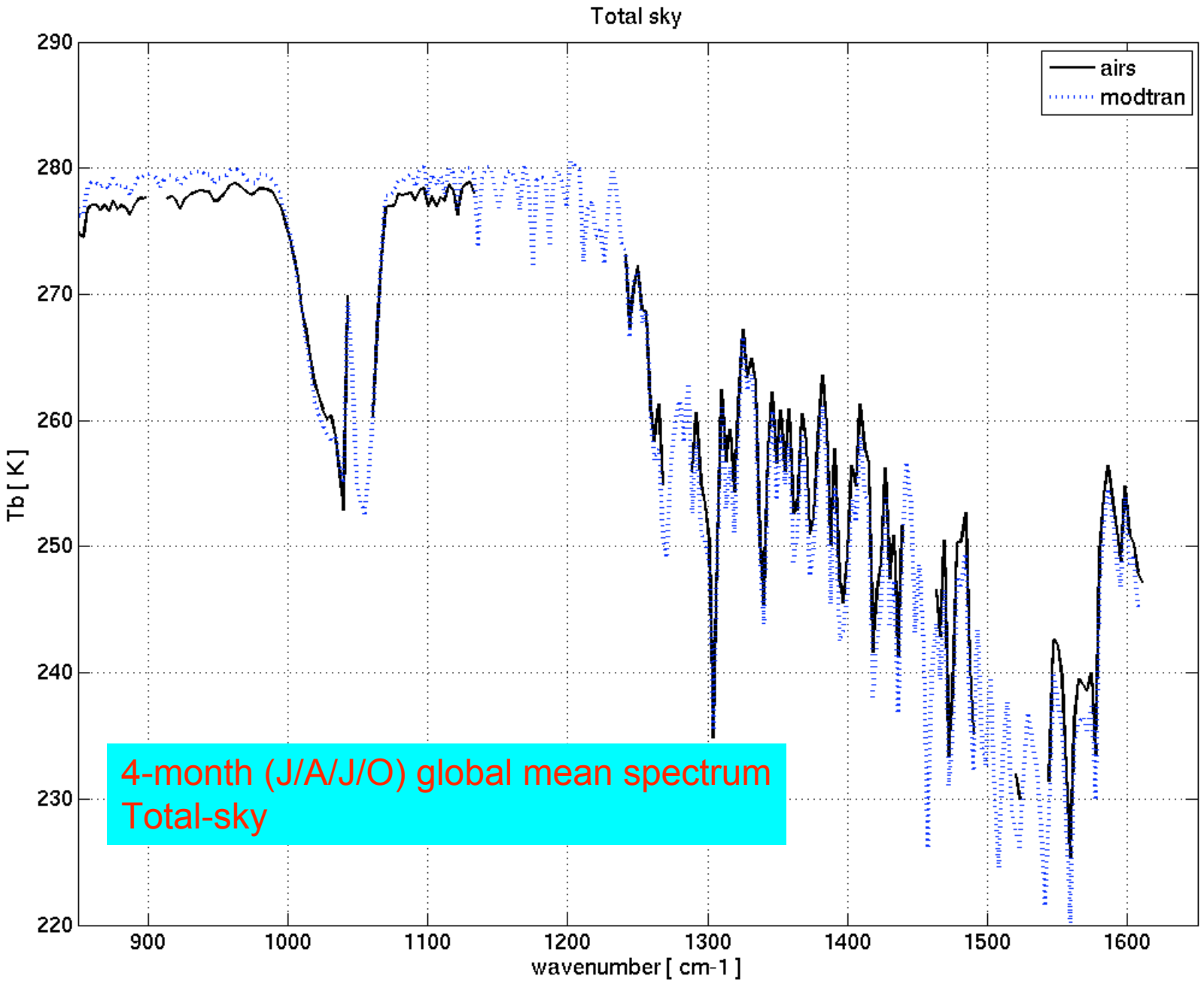


"All": random overlapping
Others: maximum overlapping weighted with tweaked cloud amount

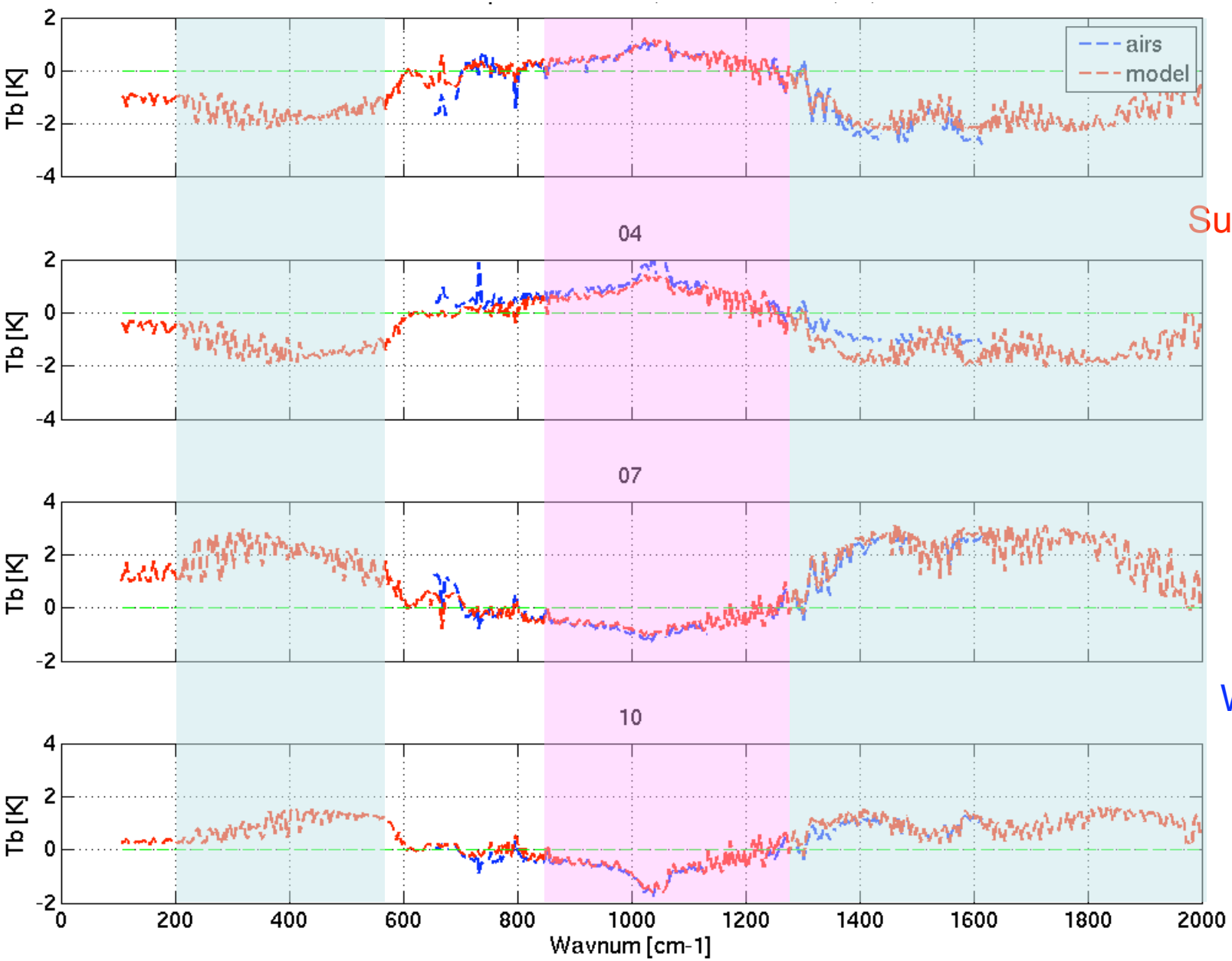
Model-Satellite Comparison

- AIRS L1B: ~ four years data are now available at GFDL
- Four selected months: Jan/Apr/Jul/Oct. 2003.
- 32 consecutive days for each monthly mean (to limit the sampling bias due to the precession cycle).
- Oceanic grids – to avoid uncertainties in the land surface emissivity.
- All radiances are degraded to 2 cm^{-1} frequency bands with a triangular scanning function.
- Comparisons
  - Diurnal mean
  - Diurnal difference (1:30pm – 1:30 am)

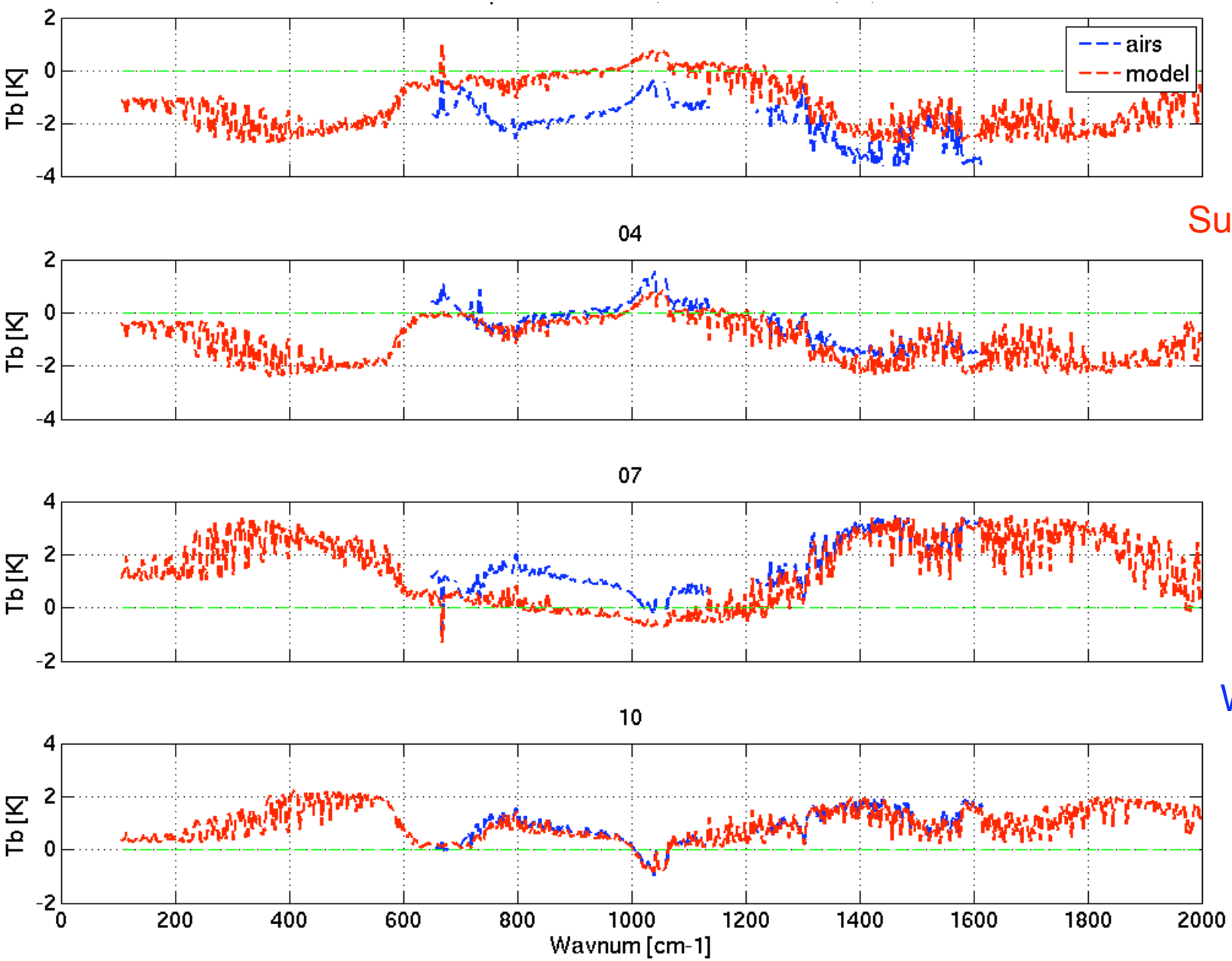

Clear sky
airs
modtran
sarta
Tb [K]
wavenumber [cm-1]
290
280
270
260
250
240
230
220
900
1000
1100
1200
1300
1400
1500
1600
4-month (J/A/J/O) global mean spectrum
Clear-sky


Total sky
airs
modtran
Tb [K]
wavenumber [cm-1]
290
280
270
260
250
240
230
220
900
1000
1100
1200
1300
1400
1500
1600
4-month (J/A/J/O) global mean spectrum
Total-sky

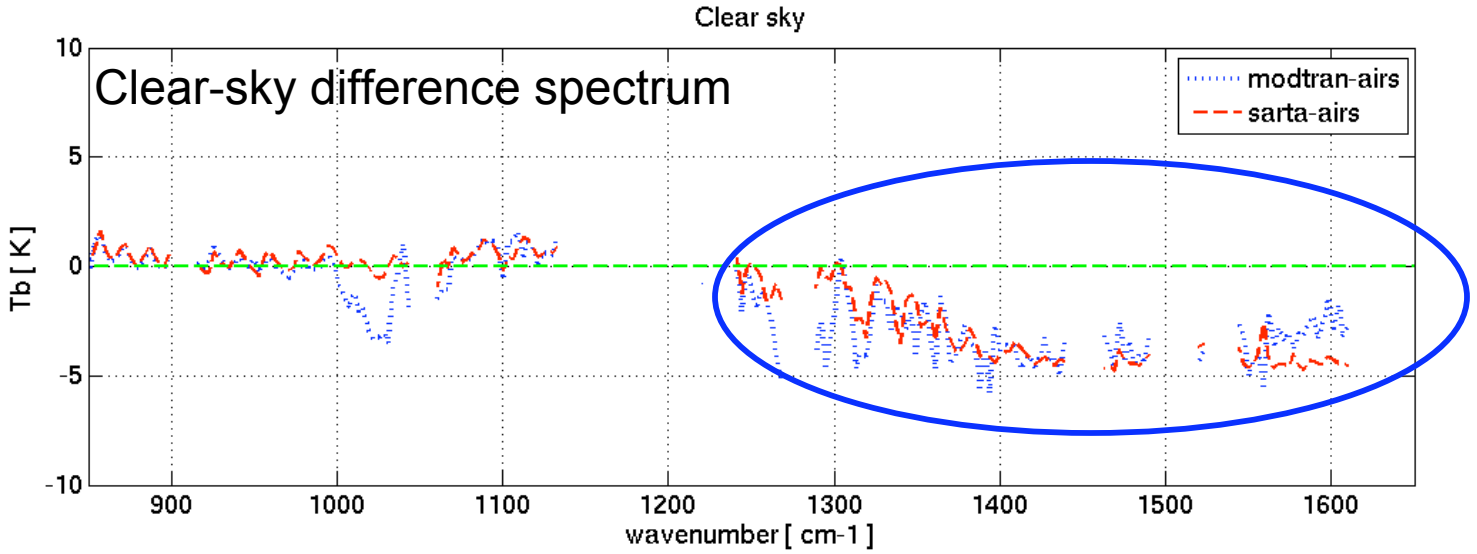
Spectrum Anomaly, clear-sky, southern tropical ocean (30s-0)

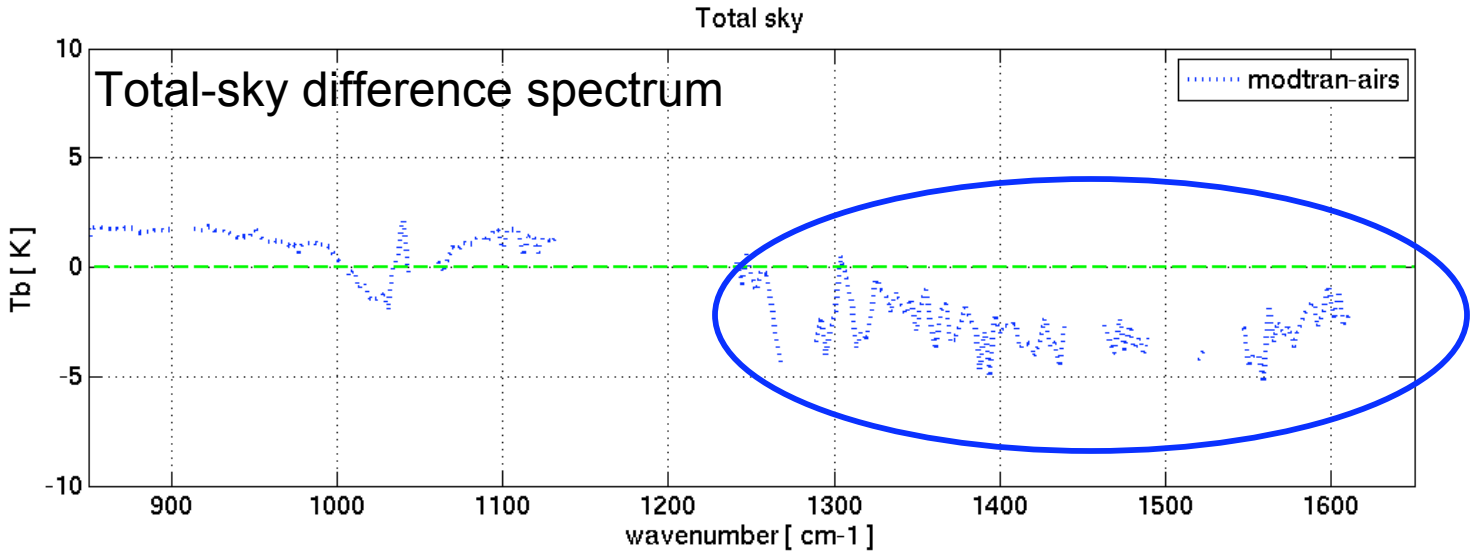


Spectrum Anomaly, total-sky, southern tropical ocean (30s-0)



Persistent cold bias in the water vapor band

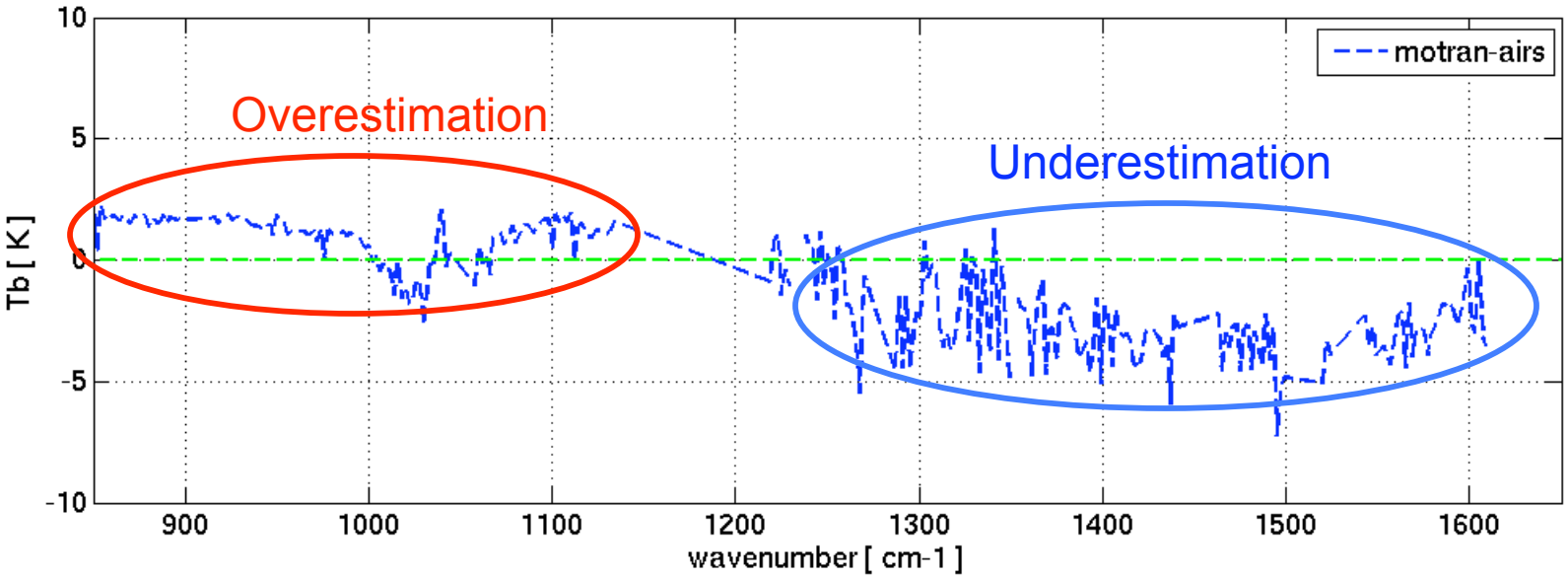




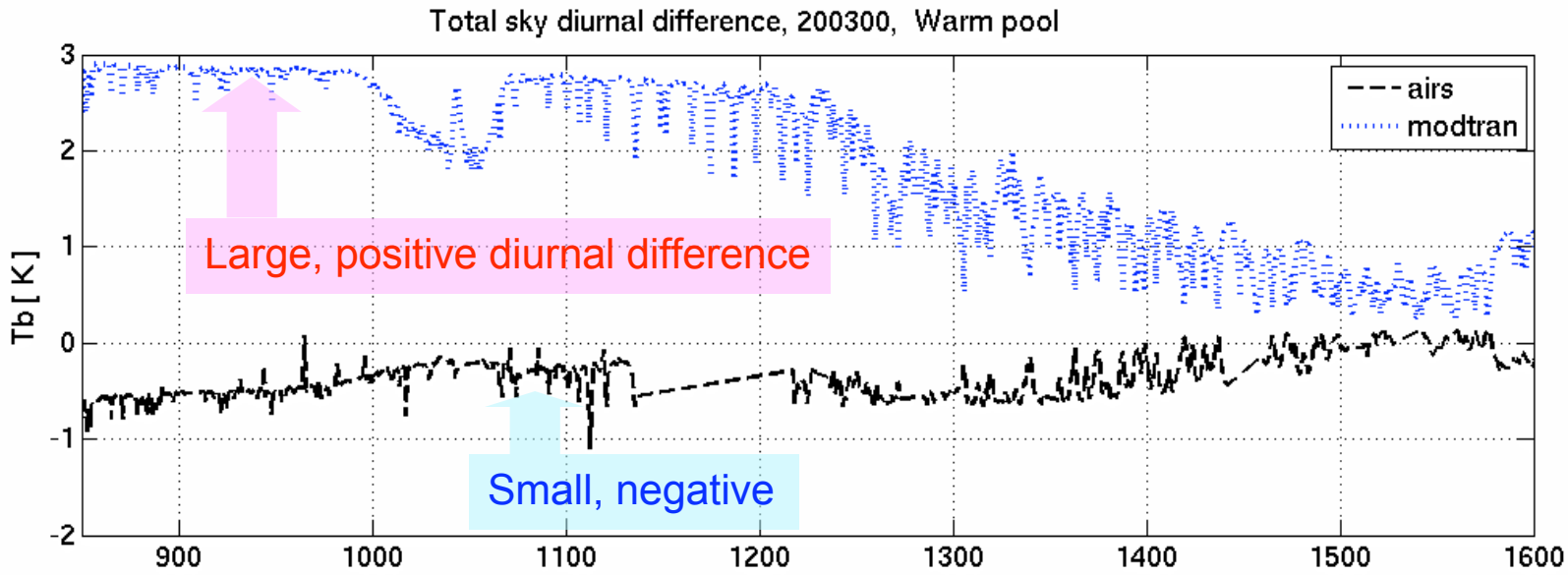
Offsetting errors

The seemingly good agreement (-1.1 W m-2 difference) of the total-sky OLR broadband flux may be fortuitous and arise due to a cancellation

Unit: W m^{-2}	OLR		Window band	
	Total sky	Clear sky	Total sky	Clear sky
CERES	**241.73**	**275.87**	**66.94**	**83.28**
AM2	**240.63**	**263.43**	**73.99**	**87.56**
AM2-CERES	**-1.10**	**-12.44**	**7.05**	**4.28**



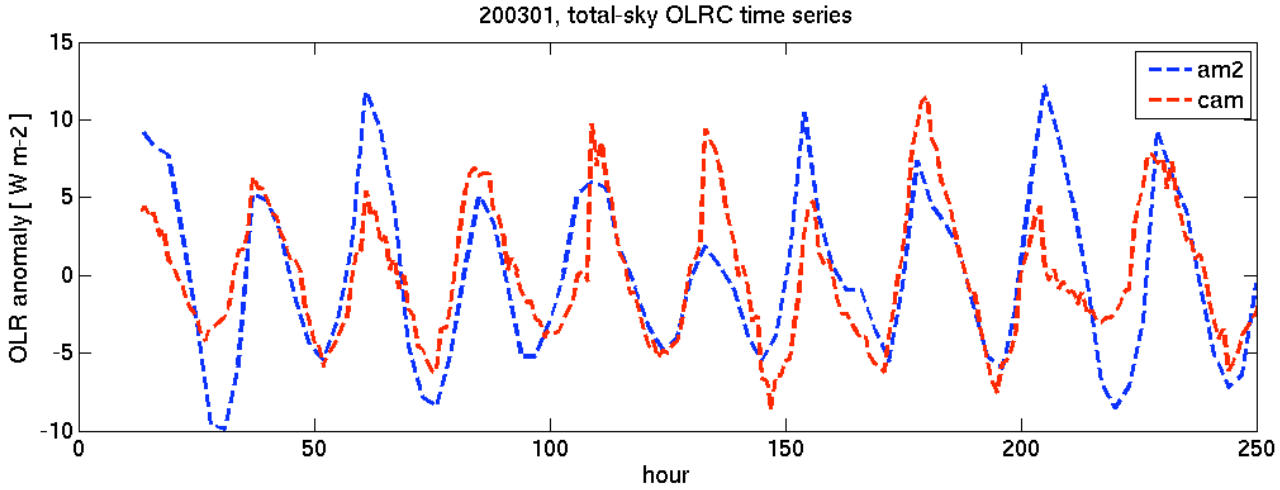
Model bias in diurnal difference spectrum



In equatorial ocean, model simulated total-sky radiances have a strong diurnal contrast at the two AIRS observation times (1:30p.m. – 1:30a.m.), which does NOT exist in the observation.

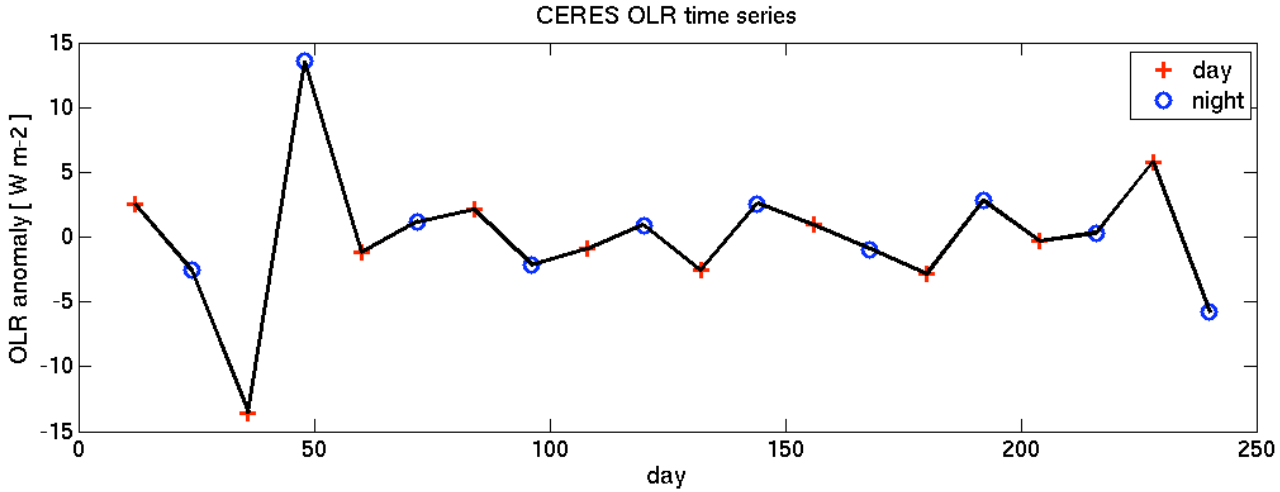
Spurious diurnal contrast in the model

Very regular diurnal variation in models: am2 (blue); cam3 (red)



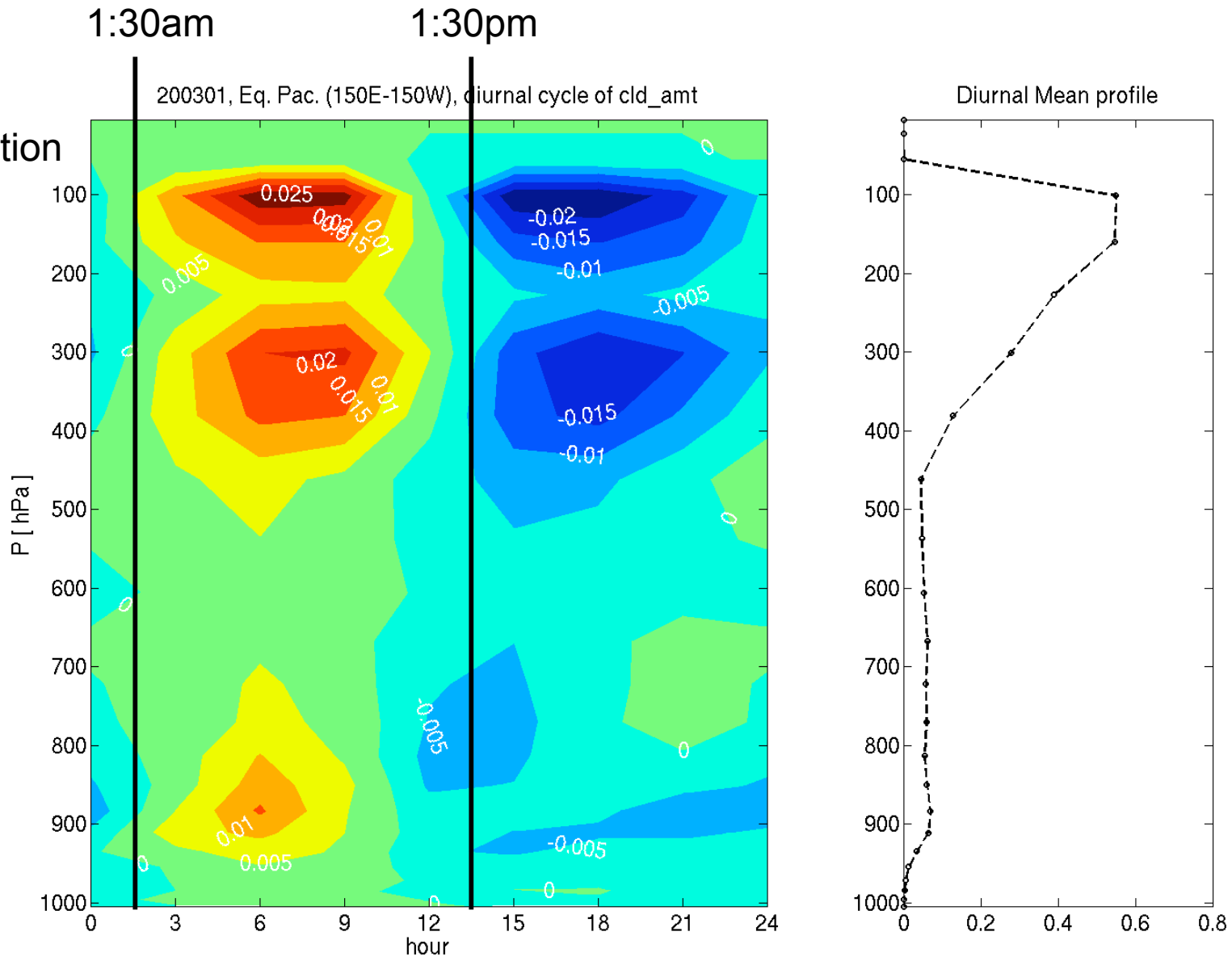
Diurnal D(OLR): [W m-2]
CERES: -0.91
AM2: 8.06
CAM3: 7.56
NCEP: 12.56

Random in obs. (CERES): day (red cross); night (blue circle)



Cause and impact?

AM2
Cld fraction



Conclusions

- Satellite observed infrared spectrum provides a more strict and insightful test for climate models than the broadband radiation flux.
  - Persistent cold bias in water vapor band indicates wet/cold upper tropospheric bias in model.
  - A seemingly good broadband flux agreement may be due to a cancellation of errors of opposite signs in different spectral regions.

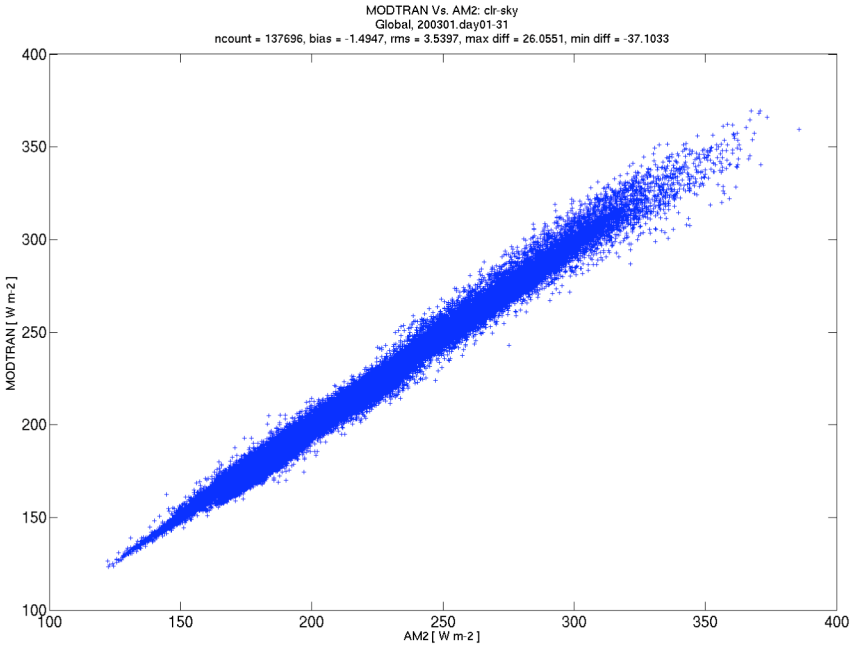
- The twice daily AIRS observations provide a reference to check model simulated diurnal variation.
  - Spurious contrast in model simulated OLR spectrum and broadband flux over equatorial oceans => errors in model simulated diurnal cycle of convection and cloudiness.
  - Such an error also emerges in the NCAR CAM and NCEP reanalysis.

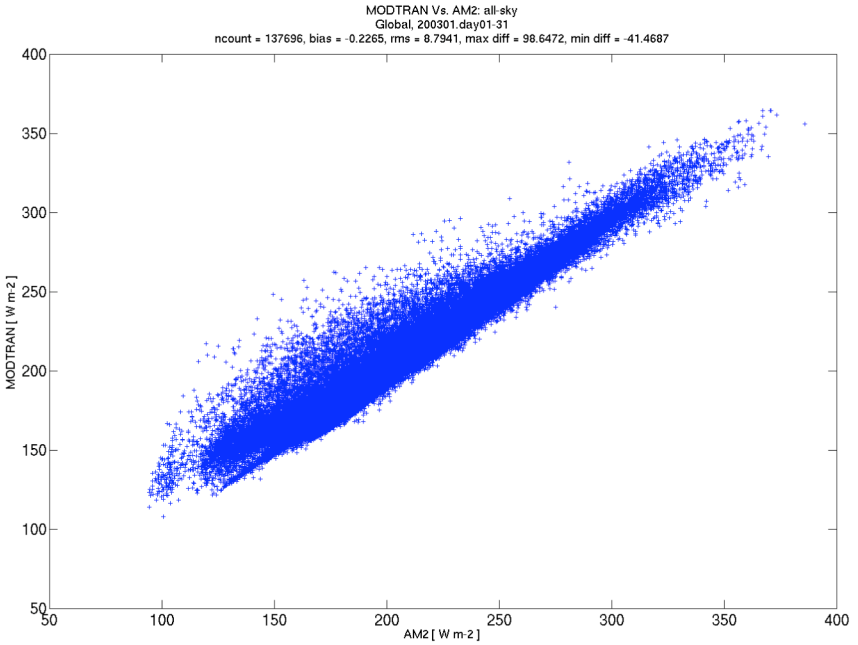
- Technical notes:
  - Satellite tracking and computation of instantaneous spectra are necessary.
  - In terms of total sky spectrum, the treatment of cloud overlapping may greatly affect the simulated radiances.

Thanks!

Consistency in R.T. simulations: MODTRAN Vs. AM2

- Broadband OLR flux
- Number of points: 137696
- Clear-sky:
  - Bias = -1.49 [W m^{-2}]
  - RMS = 3.53 [W m^{-2}]
  - Diff_max = 26.06 [W m^{-2}]
  - Diff_min = -37.10 [W m^{-2}]
- Total-sky:
  - Bias = -0.23 [W m^{-2}]
  - RMS = 8.79 [W m^{-2}]
  - Diff_max = 98.65 [W m^{-2}]
  - Diff_min = -41.47 [W m^{-2}]





AM2

	Jan	Apr	Jul	Oct
t_surf	299.8	300.1	297.7	297.6
olr	254.1	255.7	264.8	265.3
olr_clr	281.9	282.6	284.9	284.0
tot_cld_amt	59.1	56.7	53.6	54.0

	R_? (1-200)	R_h2o (200-560)	R_co2 (560-830)	R_window (830-1000, 1100-1250)	R_o3 (1000-1100)	R_h2o (1250-2000)	R_? (2000-2500)
Tropics	9.43 3%	90.79 31%	69.99 24%	83.18 29%	19.38 7%	15.99 5%	2.48 1%
MLS	9.52 3%	89.74 32%	70.36 25%	78.55 28%	16.78 6%	15.33 5%	2.16 1%
MLW	9.27 4%	84.33 36%	58.3 25%	55.84 24%	11.11 5%	11.94 5%	1.04 .5%
Te dR/dTe		260 0.9		290 1.3		260 0.4	